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None

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G1N

(54) Cardio-respiration transducer

(57) A laminated, sheet-like transducer which produces an output signal in response to changing mechanical forces F applied thereto includes a top flexible plate 16t with a matrix of uniformly spaced-apart convex members 22t on one surface and a bottom flexible plate 16b with a similar matrix of members 22b. The convex members on the surface of one plate are aligned with the spaces between the convex members of the other. A synthetic resin polymer electret film 18 is sandwiched between the convex members of each plate and becomes deformed when the convex members press against and horizontally stretch the electret film due to the changing mechanical forces F applied to the transducer. Electrodes 30 are connected to opposite surfaces of the electret film 18 and form uniformly spaced-apart electrically interconnected arrays. The electrodes sense the electrical charges in the electret film 18 and produce a signal proportional to the magnitude of the changing mechanical forces which induce the electrical charges.

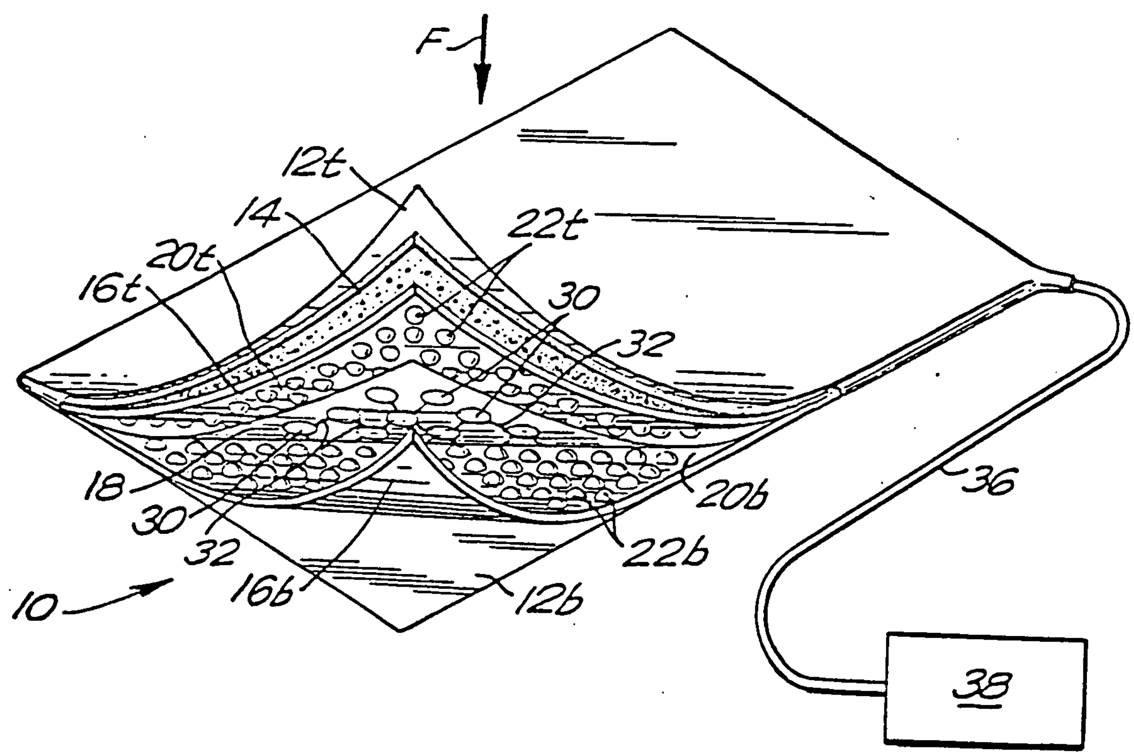

FIG. 1

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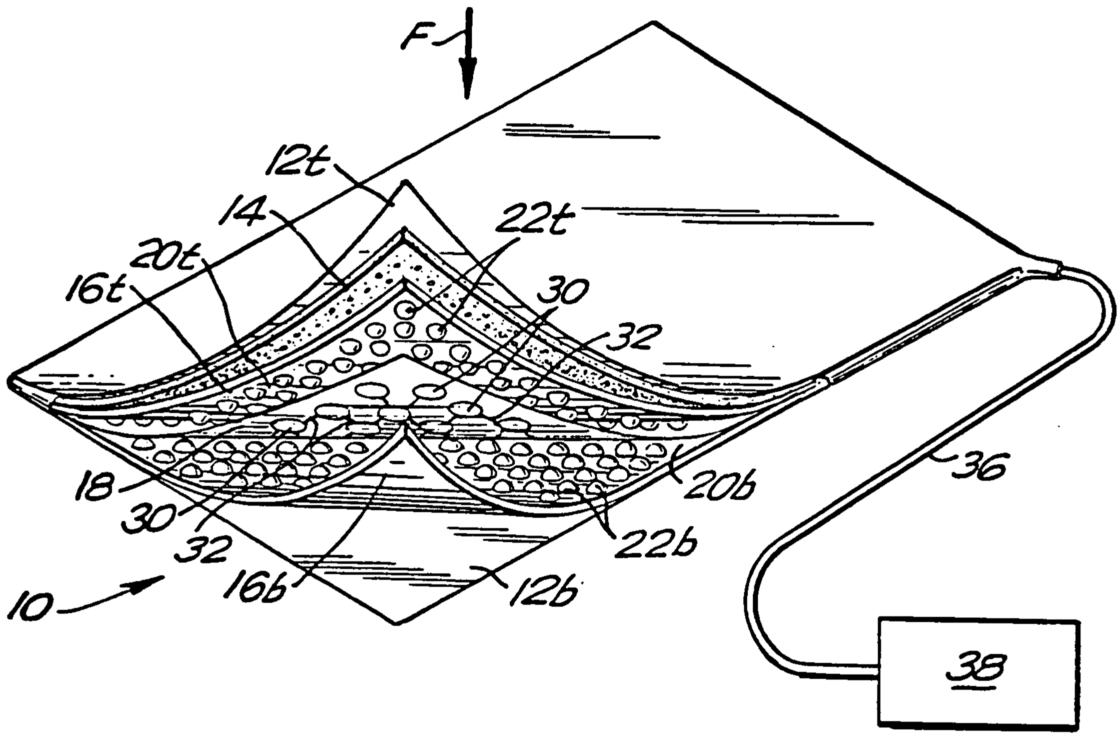
F
12t
14
22t
20t
16t
30
32
18
30
32
16b
12b
20b
22b
36
38
10

FIG.1

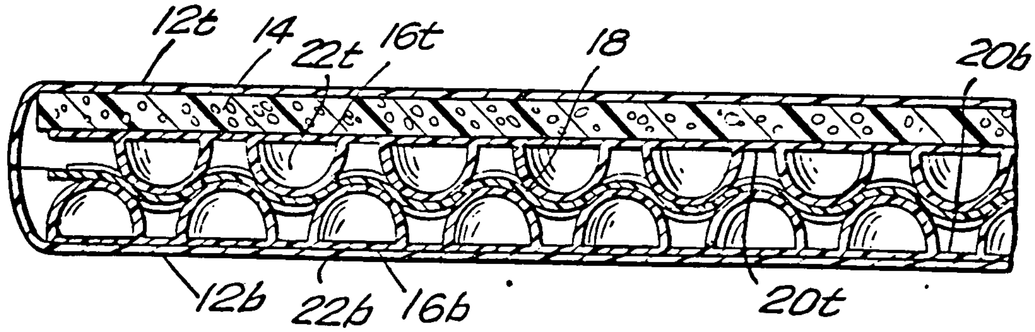
12t
14
22t
16t
18
20b
12b
22b
16b
20t

FIG.2

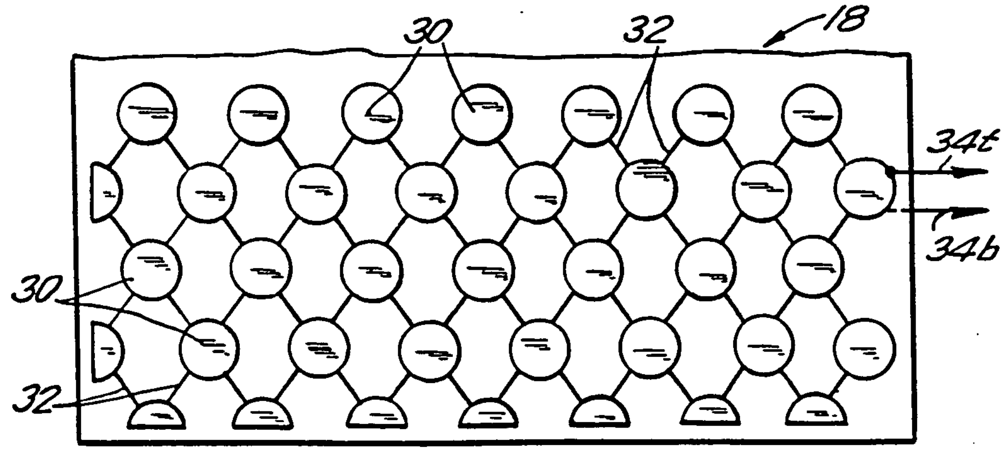

FIG.3

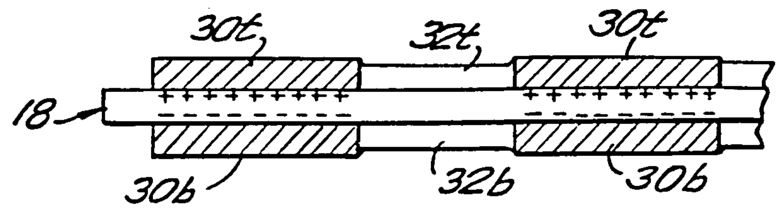

FIG.4

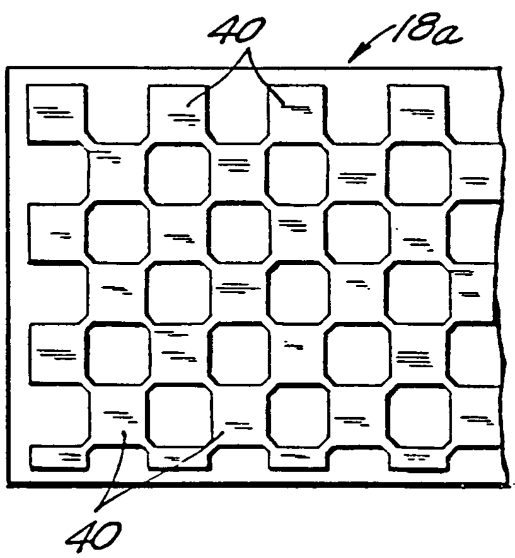

FIG.5

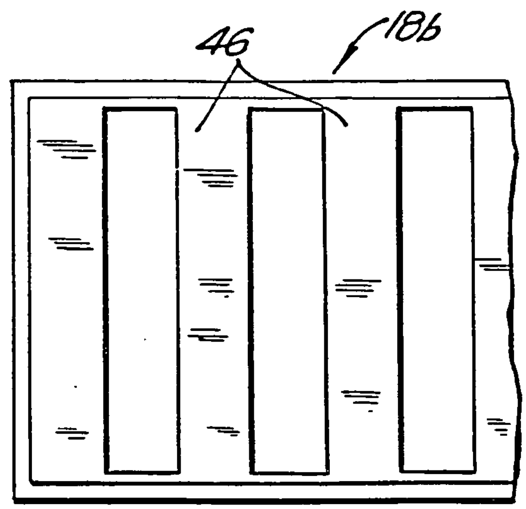

FIG.6

SPECIFICATION

Cardio-respiration transducer

This invention relates to piezoelectric transducers that are responsive to changing mechanical forces applied thereto. The changing mechanical forces may be produced by respiratory or cardiac activity of patients.

The piezoelectric transducer is made of material which produces an electrical charge that is proportional to the degree of strain in the piezoelectric material due to the motion of a mass exerting a force thereon. An electrical potential develops along certain crystallographic lattice axes of the material in response to movement of charge as a result of mechanical deformation of the material. The crystal lattice structure of the material is physically deformed by application of an increasing force caused by the moving mass. The deformation of the lattice produces a relative displacement of the positive and negative charges within the crystal lattice internal to the material. The displacement of the internal charges produce equal external charges of opposite polarity on the opposite surfaces of the material creating the "piezoelectric effect". The charges may be measured by applying metal contacts or electrodes to the opposite surfaces of the piezoelectric material and measuring the potential difference between them. The magnitude and polarity of the induced surface charges are proportional to the magnitude and direction of the applied force, produced by the moving mass, as given by:

Q (coulombs) = d (coulomb/m^2/newton/m^2) F (newtons/m^2) where Q is the surface charge, d is the piezoelectric constant and F is the applied force.

The piezoelectric transducer may be considered electrically equivalent to a charge generator, delivering a charge proportional to the force applied to the piezoelectric material. The piezoelectric transducer may be connected to a charge-to-voltage converter so that the electrical charge provided to the converter is proportional to the rate of change of the force applied or deformation of the transducer.

It is possible to induce the "piezoelectric effect" in certain synthetic resin polymers (organic compounds) by cooling them from a liquid or soft state to the solid state in the presence of an electric field or by polymerization in the presence of an electric field. Typical materials used to make such piezoelectric transducers (electret transducers) are beeswax and polymers such as polyvinylidene fluoride. For example, U.S. Patent 3,792,204 shows a transducer composed of a piezoelectric film of a polyvinylidene fluoride resin having electro-conductive material on the opposite surfaces of the film. The molecules of the film are orientated by stretching the film. The "piezoelectric effect" is produced when a force is applied perpendicular to the plane of the film causing deformation of the film parallel to the direction of molecular orientation. The transducer uses the electret of a vinylidene fluoride resin film as a vibrator or oscillator to provide for an acoustic transducer. U.S. Patent 3,996,922, which is a divisional of U.S. Patent 3,898,981, shows a force responsive transducer that senses changes due to reciprocating forces and motions caused by respiration or heart rate. The force responsive electret transducer has movable parts adapted for placement beneath a patient or a patient support such as a mattress. There is no direct attachment of the transducer to the patient. The protective covering material for the transducer is vinyl, the electrodes attached to the electret material are flexible steel sheets and the electret film is Teflon. The normal breathing motion of the patient produces a varying applied force against the electrodes. The increasing force causes the electrodes to be moved nearer the electrically polarized film in a manner similar to moving a conductor through an electric field such that a current flows through a conductor connecting the electrodes to electronic circuitry. The current flow in the conductor varies with the force applied to the electrodes which, in turn, varies with the patient's respiration rate.

With the application of a high (polarizing) voltage to produce the electric fields for inducing the "piezoelectric effect" in suitable materials, there is a reorientation of the crystalline structure which persists after removal of the polarizing voltage. Often this induction process is carried out at an elevated temperature. This technique, in addition to producing a material with a high piezoelectric constant, removes the geometrical constraints of crystallo graphic axes and makes it possible to cast piezoelectric materials in any desired form.

A piezoelectric material need be distorted only a small amount to obtain a voltage in the fractional volt range. For this reason, piezoelectric material may be considered as efficient isometric transducers. The stiffness of piezoelectric materials is usually high, and the permissible deformations are small. For example, the deformation of the crystal material used in phonograph pickups is ten (10) microns per gram of weight.

An output voltage cannot be maintained by the piezoelectric material when a sustained force is applied. Therefore, piezoelectric material is generally suited to the measurement of changing mechanical forces. Piezoelectric material can produce an output voltage for changes in mechanical deformation having a frequency of a few Hertz to many megaHertz. The upper frequency limit is determined by the total mass and stiffness of the moving transducer.

U.S. Patent 4,144,877 issued to Frei et al shows piezoelectric electret transducers made of organic compounds which are formed by cooling from the liquid or soft state to the solid state in the presence of an electric field or by polymerization in the presence of an electric field. Typical materials used to make electrets are beeswax and polymers such as polyvinylidene fluoride. Conducting electrodes are deposited on the electret material by known means and can be in an array configuration.

U.S. Patent 4,204,135 issued to Murayana shows organic piezoelectric elements in which the shifting of the piezoelectric modulus by the influence of stretching conditions is not as large for an unoriented vinylidene fluoride copolymer as for a

vinylidene fluoride homopolymer.

Other pertinent patents include U.S. Patent 3,820,529 issued to Gause et al and U.S. Patent 4,299,233 issued to Lemelson.

It is an object of this invention to provide a transducer with a synthetic resin polymer electret suitable for monitoring both respiratory and cardiac activity of a patient.

Another object of this invention is to provide a transducer, responsive to changing mechanical forces, that operates in a relatively low frequency bandwidth.

A further object of this invention is to provide for a transducer having both high sensitivity to changing mechanical forces and noise immunity.

The invention provides a laminated, sheet-like transducer which is electrically connectable to electronic circuit means and responsive to changing mechanical forces applied thereto. The transducer comprises a top flexible plate including a first surface having a matrix of uniformly spaced-apart first convex members and a bottom flexible plate including second surface with a matrix of uniformly spaced-apart second convex members aligned with the spaces between the first convex members. An electret film made of a synthetic resin polymer is sandwiched between the first and second surfaces of the top and bottom plates whereby the electret film produces electrical charges when deformed due to the first and second convex members pressing against and horizontally stretching the electret film in response to the changing mechanical forces. Electrodes are attached to opposite surfaces of the electret film and form, at least on one surface, a uniformly spaced-apart electrically interconnected electrode configuration, whereby the electrodes sense the electrical charges to produce a signal transmittable to the electronic circuit means which is proportional to the magnitude of the changing mechanical forces.

The transducer of the invention is not connected directly to the patient, is easy to use and can be adapted for use by adults as well as children to give an accurate indication of both heart and respiratory activity regardless of the patient's position on the transducer.

The invention will now be further described by way of example with reference to the accompanying drawings, in which:-

Figure 1 is a perspective view of a sheet-like, laminated transducer of the invention with portions thereof separated to show the laminations;

Figure 2 is a cross-sectional view of the transducer of Figure 1;

Figure 3 is a planar view of a metallized surface of the piezoelectric material of the transducer of Figure 1 showing one electrode configuration;

Figure 4 is a cross-sectional view of the metallized piezoelectric material of Figure 3;

Figure 5 is a planar view of a metallized surface of the piezoelectric material of the transducer of Figure 1 showing another electrode configuration; and

Figure 6 is a planar view of a metallized surface of the piezoelectric material of the transducer of Figure 1 showing yet another electrode configuration.

As shown in Figure 1, a sheet-like, laminated transducer 10 includes top and bottom protective layers 12t and 12b, foam padding 14, top and bottom resilient plates 16t and 16b and piezoelectric material 18 having electrically interconnected metallized surfaces thereon.

Specifically, transducer 10 may be placed in predetermined position with respect to a patient in order to respond to the patient's heart rate and respiration rate. Because of this use, transducer 10 may be referred to as a cardio-respiratory transducer. The transducer is adapted for placement between a patient and a patient support, such as a mattress, for sensing changes in the mechanical forces caused by the patient's cardiac and respiratory acitivity and may be used as an integral part of an apnea detecting system. The sheet-like transducer may be made to fit the size of any mattress in order to be responsive to the substantially vertical, cyclical motions transmitted to the transducer by the patient's heart beat and respiration regardless of the patient's position on the mattress. Furthermore, the transducer does not come into direct contact with the patient's body and is not adapted for application to any part of the patient's body.

Top and bottom protective layers 12t and 12b may be made of an elastic vinyl material bonded together at the edges to enclose the other components of laminated cardio-respiratory transducer 10 for providing protection against moisture and wear and tear due to normal use.

Foam padding 14 is a dense polyurethane foam and provides for a uniform distribution of the changing mechanical force (F) which is applied to the transducer as indicted by the arrow in Figure 1.

Top and bottom resilient, flexible plates 16t and 16b are made of air-filled polyethylene. On first surface 20t of top resilient plate 16t are a plurality of uniformly spaced-apart first convex members 22t forming a matrix thereon. On second surface 20b of bottom resilient plate 16b are a plurality of uniformly spaced-apart second convex members 22b forming a matrix thereon. First and second surfaces 20t and 20b of top and bottom plates 16t and 16b are proximal to one another.

Piezoelectric material 18 (an electret) is a polarized fim made of polyvinylidene fluoride (PVDF). The PVDF film carries a permanent electrical polarization or voltage between opposing surfaces thereof. As a result, one surface of the film has a positive polarity and the opposite surface has a negative polarity thereby producing an electric field across the film. Piezoelectric material 18 has attached thereto on both surfaces metallized areas which will be discussed below.

For this invention, the laminated, sheet-like cardio-respiratory transducer has the structure shown in Figure 2. Piezoelectric material 18 is sandwiched between first and second surfaces 20t and 20b of top and bottom r silient plates 16t and 16b. The convex members on the surface of one plate are in alignment with the spaces between convex members on the surface of the other plate. Foam padding 14 is placed over the resilient plates proximal to top plate 16t and distal to bottom plate 16b. Top and bottom

protective layers 12t and 12b are bonded together at their edges as shown in Figure 2, to provide protection for the piezoelectric material, plates and padding enclosed therein.

Metal contacts or electrodes (metallized areas) are attached to both surfaces of piezoelectric material 18 for sensing the induced surface charges which are proportional to the magnitude and direction of the applied force, F, as explained above. In this embodiment, a plurality of metal disc-shaped electrodes 30, as shown in Figures 3 and 4, are attached to piezoelectric material 18. The plurality of metal disc electrodes are uniformly spaced-apart from one another over substantially the entire surface area of the piezoelectric material and are arranged in a rows and staggered columns configuration, i.e. a matrix. Each disc is electrically connected to another disc obliquely or diagnolly positioned with respect to it, by electrical leads 32. The electrically interconnected matrix configuration of the metal disc electrodes may be attached, i.e. by vapour deposition, to one surface of the piezoelectric material while the opposite surface has one common electrode or both surfaces may have attached thereto the metal electrode matrix configuration shown in Figure 3. It will be recognised by those skilled in the art that the metal electrodes may be of substantially any shape, i.e. square, triangular, or rectangular, and the configuration or electrode pattern may be different without altering its purpose or function.

Figure 4 shows the position of the disc electrodes with respect to each other on either side of the piezoelectric material when both surfaces of the material have the above described metal disc electrode configuration. Electrodes 30t on one surface are substantially directly aligned with electrodes 30b on the opposite surface of the piezoelectric material. The electrodes sense or "pick up" the external surface charges (++++ and − − − −) produced by the displacement of the internal, lattice charges caused by the mechanical deformation of the crystallographic lattice axes of piezoelectric material 18 due to the motion of a mass exerting a force thereon. Electrodes 30t are electrically connected by leads 32t and electrodes 30b are electrically connected by leads 32b. The electrodes only "pick up" the external charges closest to each electrode. The charges at the electrodes produce a signal between output leads 34t and 34b proportional to the magnitude of the changing mechanical forces exerted by the mass on the transducer. Output leads 34t and 34b, are electrically connected to disc electrode configurations on the top and bottom of piezoelectric material 18, respectively, as shown in Figure 3. The output signal is transmitted via output leads 34t and 34b to monitoring means 38 along cable means 36 as shown in Figure 1. The monitoring means, including a charge-to-voltage converter, and cable means are collectively defined as electronic circuit means for processing the output signal and displaying cardiac and respiratory activity.

The cardio-respiratory transducer, described above, must be supported by a mattress but may be under the mattress sheet. When a substantially vertical force is applied to transducer 10, as shown in Figure 1, external charges are formed on the surfaces of the PVDF film which are "picked up" by disc electrodes 30, i.e. electrodes 30t on one surface and electrodes 30b on the opposite surface of piezoelectric material 18 as shown in Figure 4. The external surface (electrical) charges are produced by the deformation of the crystallographic lattic axes of the PVDF film as the film is stretched horizontally when first and second convex members, 22t and 22b, press against opposite surfaces of the piezoelectric material due to the substantially vertical mechanical force applied to the transducer.

The size of each disc electrode will vary depending upon the size of the patient since, during respiration, the patient's centre of gravity will shift producing a transducer output signal in the manner described above. Generally, infants would require disc sizes of from approximately 1.5 to 2 inches (3.8 to 5.08 cm) in diameter where the space between adjacent discs would be appoximately 2 inches (5.08 cm). Adults would require disc sizes of from approximately 4 to 5 inches in diameter (10.16 to 12.7 cm) where the spacing between adjacent discs would be approximately 5 inches (12.7 cm).

The disc or first uniformly spaced-apart electrode configuration shown in Figure 3 is responsive to a patient's cardiac activity (heart beats) and respiratory activity when the patient is lying on the mattress, i.e. on the transducer. However, the electrode configuration shown in Figure 5 is also capable of detecting horizontal translation of the centre of gravity due to respiratory activity as well as substantially vertical displacement due to cardiac activity. Checkerborad or second uniformly spaced-apart electrode configuration 40 provides spaced-apart sensitive and non-sensitive areas for responding to the turning moment produced by a patient's respiratory activity as well as for responding to vertical displacement produced by a patient's cardiac activity. The checkerboard electrode configuration of Figure 5 is attached to piezoelectric material 18a and each electrode therein is electrically connected to other electrodes and to the electronic circuit means substantially in the manner described above for the disc electrode configuration. When used with infants, each square-shaped electrode in the checkerboard configuration is approximately 50 mm on a side. The spacing between adjacent squares is approximately 50mm.

Rectangular or third uniformly spaced-apart electrode configuration 46 is shown in Figure 6. The rectangular electrode configuration of Figure 6 is attached to piezoelectric material 18b and each rectangular-shaped electrode therein is electrically connected to other rectangular-shaped electrodes and to the electronic circuit means to form a complete circuit substantially in the manner described above for the first and second uniformly spaced-apart electrode configurations. It would be obvious to one skilled in the art that the electrodes may be shaped and configured in a variety of ways. The configuration in Figure 6 may be used for adults as well as for children.

For all electrode configurations, the size of each

convex member on each plate must be much smaller than the size of each electrode. In the above two embodiments, the size of each convex member is approximately one quarter inch (0.635 cm) in diameter.

Even though the rather stiff PVDF film has a thickness of approximately 28 microns in all cases, the length and width of the sheet-like transducer is not limited except for the practical constraints due to the size of the mattress. The optimal position of the transducer would be between the patient and the mattress, i.e. under the mattress sheets. However, at no time does the transducer come into direct contact with the patient's body. Furthermore, the transducer is not connected to the patient in any way, i.e. as around an arm or a leg.

In the present invention, the "piezoelectric effect" is induced into a PVDF film at a temperature of between approximately 60° to 100° C while the film is stretched uniaxially up to four times its initial length. The electrodes (disc-shaped, square-shaped, rectangular-shaped, etc.) are then deposited by evaporization on predetermined portions of the surfaces of the piezoelectric material in a predetermined configuration as shown in Figures 3, 5 and 6. These steps must be performed before transducer 10 is assembled. To polarize the PVDF film before assembly, a high DC voltage must be applied between the deposited electrode matrices on either side of the PVDF film for approximately one hour at a temperature of approximately 80° to 100° C. If the transducer is assembled with an unpolarized PVDF film, the transducer may be heated and polarized via cable means 36 as shown in Figure 1. The sensitivity of the sheet-like laminated transducer of the present invention is dependent upon the thickness of the PVDF film and the DC voltage used to polarize it. The dielectric strength of the piezoelectric material is a limiting factor in achieving a high sensitivity. The transducer operates within a 0.1 to 10 Hertz bandwidth and is capable of responding to respiratory activity as well as cardiac activity.

CLAIMS

1. A laminated, sheet-like transducer electrically connectable to electronic circuit means and responsive to changing mechanical forces applied to said transducer, comprising a top flexible plate including a first surface having a matrix of uniformly spaced-apart first convex members, a bottom flexible plate including a second surface having a matrix of uniformly spaced-apart second convex members aligned with the spaces between said first convex members, an electret made of a synthetic resin polymer sandwiched between said first and second surfaces of said top and bottom plates whereby said electret produces electrical charges when deformed due to said first and second convex members pressing against and horizontally stretching said electret in response to said changing mechanical forces, and electrodes attached to opposite surfaces of said electret, said electrodes forming a uniformly spaced-apart, electrically interconnected electrode configuration on at least one surface of said electret, whereby said electrodes sense said electrical charges producing a signal transmittable to said electronic circuit means which is proportional to the magnitude of said changing mechanical forces.

2. A transducer according to Claim 1 in which top and bottom protective layers enclose said top and bottom flexible plates and said electret and are bonded together at their edges.

3. A transducer according to Claim 2 in which foam padding is provided between said top protective layer and said top flexible plate.

4. A transducer according to Claim 1 in which said electret is made of polyvinylidene fluoride.

5. A transducer according to Claim 1 in which said uniformly spaced-apart electrodes are disc-shaped.

6. A transducer according to Claim 5 in which said disc-shaped electrodes are arranged in a rows and staggered columns matrix configuration.

7. A transducer according to Claim 6 in which each of said disc-shaped electrodes is electrically connected to another of said disc-shaped electrodes obliquely positioned with respect thereto.

8. A transducer according to Claim 6 in which said matrix configuration of disc-shaped electrodes is attached to at least one surface of said electret by vapour deposition.

9. A transducer according to Claim 1 in which said uniformly spaced-apart electrodes are square-shaped.

10. A transducer according to Claim 9 in which said square-shaped electrodes are arranged in a checkerboard configuration.

11. A transducer according to Claim 1 in which said uniformly spaced-apart electrodes are rectangular-shaped.

12. A transducer according to Claim 1 in which said changing mechanical force is applied substantially perpendicular to said transducer.

13. A transducer according to Claim 1 in which said changing mechanical force acts over a predetermined distance of said electret producing a turning moment.

14. A transducer according to Claim 2 in which said protective layers are vinyl.

15. A transducer according to Claim 4 in which said polyvinylidene fluoride is approximately 28 microns thick.

16. A transducer according to Claim 5 in which said disc-shaped electrodes are from approximately 1.5 to 2 inches (3.8 to 5.08 cm) in diameter.

17. A transducer according to Claim 15 in which the spacing between adjacent discs is approximately 2 inches (5.08 cm).

18. A transducer according to Claim 5 in which said disc-shaped electrodes are from approximately 4 to 5 inches (10.16 to 12.7 cm) in diameter.

19. A transducer according to Claim 17 in which the spacing between adjacent disc is approximately 5 inches (12.7 cm).

20. A transducer according to Claim 1 in which the diameter of each of said convex members is approximately one quarter inch (0.635 cm).

21. A transducer according to Claim 9 in which each square-shaped electrode is approximately 50

mm on a side.

22. A transducer according to Claim 20 in which the spacing between adjacent electrodes is approximately 50 mm.

23. A transducer according to Claim 1 in which said transducer operates within a bandwidth of from approximately 0.1 to 10 Hertz.

24. A transducer according to Claim 11 in which said substantially perpendicular changing mechanical force is produced by cardiac activity of said patient.

25. A transducer according to Claim 12 in which said turning moment is produced by respiratory activity of said patient.

26. A transducer according to any one of the preceding claims in which said electret film is attached to a deformable support layer.

27. A transducer according to Claim 26 in which said deformable support layer is plastics.

28. A laminated, sheet-like transducer substantially as hereinbefore described with reference to the accompanying drawings.

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